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ENGINEERING DIVISION

The Plumbicon camera tube

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THE BRITISH BROADCASTING CORPORATION

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THE PLUMBICON CAMERA TUBE

Report No. T-148
(1965/21)

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1. INTRODUCTION

The purpose of this report is to review the present technical performance of the plumbicon tube and to explore Philips' ability to supply the tubes which the Corporation may require for operation in future colour television cameras. The report discusses the current situation and arrives at the conclusions and recommendations set down in (2) below. In the main, the source of information on which the report is based was obtained during two visits to Philips in Eindhoven during February and March 1965. Also relevant are discussions with British manufacturers on their plans to develop both tubes of the plumbicon type and colour equipment incorporating the plumbicon.

It should be noted that the Philips' organisation comprises a number of Main Industry Groups, and our discussions were conducted with three of these Groups as follows:

(i) The Electronica Group, who are responsible for the development and production of the plumbicon tube.

(ii) The Electro Acoustics Group (ELA), who are responsible for the design and development of sound and television studio equipment, which includes the three-plumbicon camera.

(iii) The Research Laboratories.

2. MAIN CONCLUSIONS AND RECOMMENDATIONS

2.1. More information is required about the behaviour of the plumbicon tube under every-day operating conditions, particularly for outside broadcast use, but we consider that in all significant respects the tube in its present form has a satisfactory performance and can be adopted with confidence for use in colour cameras.

2.2. Electronica have stated clearly that they are concentrating on the production of plumbicons for colour use and are paying little attention to black-and-white applications, at least for professional broadcast purposes. This attitude has been

reflected in this country by Mullard's who have evidently written to British camera manufacturers to dissuade them from embarking on the development of black-and-white cameras based on the plumbicon, because of their inability to guarantee future supplies of tubes for this purpose. Despite this, ELA, mainly through its overseas subsidiaries, has embarked on a programme of black-and-white plumbicon camera development and it is clear that there is a division of opinion in this matter within the Philips' organisation between the tube and equipment manufacturing groups.

2.3. Work is proceeding in Philips' Research Laboratories on a plumbicon with extended red sensitivity, apparently intended specifically for use in the red channel of a colour camera. Electronica are not prepared at present to indicate a date by which this tube may be in regular production. Indeed they take the view, which we share, that the tube in its present form is satisfactory for colour use and they will not allow themselves to be stampeded into proceeding prematurely with the manufacture of a tube with extended red sensitivity.

The emphasis which is apparently being given to the work on this tube in the Research Laboratories again reflects the division of opinion within the Philips' organisation on the favoured application of the plumbicon, since the possible widespread use of the plumbicon for black-and-white operation must be inhibited by the lack of a tube with extended red sensitivity. For this reason we would regard it as uncertain that present image orthicons could be displaced to any great extent by the plumbicon until such a tube is available.

2.4. An important advance made in our discussions with Philips is that they are now prepared to guarantee a minimum average sensitivity for batches of colour tubes which will result in a useful reduction (between 12% and 15%) of the lighting level previously thought necessary for plumbicon camera operation.

2.5. Philips have been extremely frank in providing information on both their experience to date with plumbicon tube manufacture and their future plans and expectations.

They have reiterated the guarantee given previously by Mullard's regarding their ability to provide the tubes the Corporation may require for use in colour cameras. They added to this that they would give the BBC priority over other users and that their guarantees are independent of the manufacturers from whom we might purchase camera equipment.

2.6. Philips' present pre-production plant has been in use since March 1964, and figures have been obtained for the expected output of tubes from this plant for future years. Philips have plans to set up a larger production unit in Eindhoven, to come into operation in mid-1967.

In comparing Philips' planned figures for future plumbicon production with the BBC's requirements, it appears that we should require a significant proportion of their output of studio tubes in 1967, although the production for this could probably be increased by a useful amount. In the preceding and following years, our requirements would represent smaller proportions of their production.

It is felt that, despite the guarantees given by Philips, the reserve in their expected production to meet our requirements is relatively small for 1967 and some difficulty could arise in this year in the Corporation obtaining all the tubes it may want. There would, in any event, be some hazard for the Corporation in starting its colour service with plumbicon tubes when manufacture of the tubes was confined to a single plant located outside this country. There is at present no intention of setting-up a plumbicon production plant within the Mullard organisation. It is none-theless recommended that we should proceed with our plans for using plumbicons.

2.7. The plumbicon supply position is likely to be helped by the fact that both E.E.V. and E.M.I. in this country are devoting effort to the development of plumbicon tubes. This work appears still to be at a comparatively early stage, but E.E.V. at least have committed themselves to saying that they hope to produce a successful design of tube within the next two years.

2.8. Doubt has been expressed about certain aspects of the technical performance of the plumbicon. These include the ability to handle high-contrast scenes, the incidence of black level variations (flare) and the ability to reproduce skin tones in a subjectively satisfactory manner. All of these topics are under active investigation by the BBC and have been the subject of discussions with Philips. There is no apparent difficulty which could amount to a serious obstacle to the use of the plumbicon tube either for outside broadcasts or in studio operations. Technical advances in the reduction of flare to a very low level and new information concerning the operation of the tube under high-contrast conditions promise satisfactory performance under most operational conditions.

The reproduction of skin tones is a subject which needs further investigation, but it should not be concluded that the ability of a plumbicon camera in this respect is limited by the performance of the tube. It is believed at present that the subject represents a much more general problem of colour reproduction by television.

3. PLUMBICON TUBE CHARACTERISTICS

Our discussions with Electronica have covered:

(a) A review of all outstanding aspects of the technical performance of the plumbicon tube with reference to a draft of BBC Specification TV.153,[1] which has been the subject of discussion with both Mullard's and Philips during recent months.

(b) The obtaining of information on Philips' production experience to date with the plumbicon, their expectation of future production quantities and their ability to supply the tubes which the BBC may require for its colour service. These discussions were coupled with an inspection of the plumbicon pre-production* facilities which are at present in operation.

* Philips refer to the new plant for the manufacture of plumbicons which has been in use since March 1964 as a 'pre-production' facility, but this is evidently purely a matter of terminology, since the plant is in regular use as a production unit. The description merely reflects that production techniques are still the subject of change and experiment; yields are therefore relatively low and would have to be increased appreciably before the plant is regarded as a full production unit.

Some of the personnel with whom we had discussions were present at all our meetings, while others were present only at some. Those who took part were:

Dr. J.D. Stephenson (Managing Director, Electronica)
Mr. P. Brolsma (Article Manager (Professional Tubes), Electronica)
Dr. van Zanten (Technical Manager, Camera Tubes, Electronica)
Ir. J.R. Boerman (Camera Tube Measurements, Electronica)
Dr. Schut (Camera Tube Measurements, Electronica)
Mr. J. Dollekamp (Technical/Commercial, Camera Tubes, Electronica)
Mr. J.B.M. Janssens (Commercial Assistant, Professional Tubes, Electronica)
Mr. K.F. Gimson (Industrial Markets Division, Mullard's)
Mr. J.E. Wilson (Commercial Products Manager, Mullard's)

The information gained at these meetings and from other sources has been classified under the appropriate headings of tube characteristics.

3.1. Sensitivity

The latest draft of Specification TV.153 gives the minimum sensitivity to white light of the plumbicon as 275 μA/L. The sensitivities of tubes for use in the colour channels of a colour camera are, however, expressed by reference to the incident white light required to produce a specified peak signal current when a designated red, green or blue filter is introduced between the source and the tube. A series of numbers is thus obtained which give the minimum micro-amperes with the filters in place per lumen of white light before the filter.

Philips gave figures for the average sensitivity to white light and the standard deviation for the last sixty plumbicons (twenty each red, green and blue channel tubes) sent out from the factory during the preceding two or three months. These are:

TABLE 1

CAMERA CHANNEL	AVERAGE SENSITIVITY TO WHITE LIGHT (μA/L)	STANDARD DEVIATION
Red	422	26
Green	408	27
Blue	331	36

The average sensitivity to coloured light of these tubes, expressed in the terms described above, were also given by Philips, and the corresponding figures are:

TABLE 2

CHANNEL	μA OF SIGNAL CURRENT PER LUMEN OF WHITE LIGHT BEFORE FILTER	
	MINIMUM FIGURE GIVEN IN DRAFT OF TV.153	AVERAGE FIGURE MEASURED BY PHILIPS
Red	60	80
Green	125	177
Blue	32	39

Based on the measurements given in Table 2, Philips stated that they considered they could easily meet the tube sensitivities given in the draft specification. They went on to say that they felt it desirable to have some sensitivity in hand since changes they may wish to make in the processing of tubes in order to improve the overall product might result in some reduction in sensitivity. We expressed quite strongly our view that the sensitivities given in the specification were lower than we would wish and that in making changes to the tube, Philips should hesitate to trade sensitivity for improvements in other directions. We went on to suggest to Philips that they appeared, from the figures they had given for recent tubes, to be perhaps over-cautious in pitching the figures given in the specification so low. Since it was clear that the average sensitivity of batches of tubes which met the minimum sensitivity requirement would lie at a higher value than the minimum figure, we proposed to Philips that the specification should be amended by the addition of a series of guaranteed figures of average sensitivity.

Philips accepted this argument and said that they would consider what average figures they would undertake to achieve for a quantity of at least twenty-five tubes. The following figures have been confirmed in a letter from Mullard's to Planning and Installation Department dated 24th March 1965.

TABLE 3

CHANNEL	PROVISIONAL AVERAGE μA OF SIGNAL CURRENT PER LUMEN OF WHITE LIGHT BEFORE FILTER
Red	70
Green	140
Blue	36

We stated that, although the BBC would be prepared to accept the lower limits of sensitivity given in the specification, we would hope very much that these figures could be increased. Philips noted this and undertook to review the position in September 1965.

It was similarly agreed that an average sensitivity figure should be given for a quantity of twenty-five black-and-white tubes. Again, provisionally, Philips suggested that this would probably be 330 μA/L, but they reserved their position on this to the extent that they said they may not wish on reflection to give an average sensitivity figure for black-and-white tubes, since their aim is to concentrate on the manufacture of tubes for colour use, and the two requirements may to some degree be in conflict.

3.2. Resolution

It was agreed that the specification, which is now written in terms of the separate-mesh plumbicon, would express Philips' aims of achieving, in a circle of diameter equal to 0·7 of the image diagonal, a horizontal resolution of not less than 52% modulation at 5 Mc/s for a peak signal current of 0·3 μA. This will be reviewed in September 1965 after further experience has been gained with agreed test channels, separate-mesh tubes and improved scanning coils. This review may result in a relaxation of the resolution performance, but it will in any event not be worse than 44% modulation under the conditions already referred to.

At the present, Philips' measurements of resolution are made with square-wave test-bars, and the figures given above are related to this method of measurement. It is agreed that measurements shall be made in due course with sine-wave test-bars, and discussion and agreement will then be necessary to agree corresponding figures for this condition of measurement.

For comparison, a typical 4½ in. image orthicon operated in the 'colour mode' (exposure only up to the knee point, and with 4·75 V target potential) gives a horizontal resolution of 65% at 5 Mc/s. This performance is thus in the range 2·2 to 3·7 dB better than the expected performance of the plumbicon.* However, the noise performance of the plumbicon makes it possible to equalise the horizontal response satisfactorily without serious penalty.

We were shown a test camera channel in which a separate-mesh tube was operated with 700 V on the mesh and 600 V on the wall anode. A test card was reproduced with a peak signal current of 0·4 μA and no aperture correction was employed. The picture exhibited good resolution and this was well maintained out to the corners of the display.

Philips stated that the beam current can be increased to 0·6 μA without any loss of resolution and can be further increased to 1·0 μA with only a small loss of resolution.

* Marconi's have however indicated that, with a suitable design of yoke, they have obtained an uncorrected horizontal resolution response from a plumbicon of about 65% at 5 Mc/s. It is not known how typical this performance may be.

3.3. Lag

Further discussion will be necessary in due course on the precise lag figures to be included in the specification when suitable methods of measurement have been worked out and agreed. It is, however, clearly understood that the lag performance shall be subjectively satisfactory, and indeed from the tubes we have already seen there is no reason to doubt that this will be so.

One new question raised by the BBC was the maintenance of a satisfactory lag performance down to low illumination levels. It was agreed that the objective lag performance as finally settled for a normal peak signal current of 0·3 μA should substantially be maintained down to an illumination level corresponding to a peak signal current of 0·04 μA, which corresponds to the noisiest picture it is considered practicable to use.

3.4. Black Level Variation

Difficulty has been experienced due to stray light falling on the plumbicon target as a result of internal reflections in the faceplate of the tube. The flare produced in the picture has been most apparent from the variations in black level which have resulted from changes in mean scene brightness.

To overcome this effect, Philips have some tubes in which an extra glass window of about 6 mm thickness has been optically cemented to the faceplate of the tube. The window has been made 21·5 mm in diameter, i.e., approximately equal in size to the image diagonal. Measurements made in BBC Research Department show this to have a very beneficial effect.

TABLE 4

Signal level variation in a small central black area (0·1% picture area) when the surrounding field (99·9% picture area) is changed from black to peak brightness

STIMULUS	NORMAL FACEPLATE (1·2 mm THICK)	THICKENED FACEPLATE (7·2 mm TOTAL)
White light	14·0%	4·5%
Red light	24·5%	8·0%
Green light	14·0%	4·0%
Blue light	5·5%	1·0%

Tubes incorporating the thickened faceplate were operated in a plumbicon channel which we saw demonstrated at the Philips' Research Laboratories (see Section 5). The absence of flare was very marked, and the general impression of picture sharpness was very good.

We discussed with Electronica the fitting of an extra window to the tube as part of their normal manufacturing process, and this they undertook to investigate. There seems to be no reason why this should not be done and indeed it was eventually agreed to amend the tube specification to standardise on total glass thickness, between the target and the outer face of the tube, at 7·2 mm ± 1·0 mm.

This information is being conveyed to the lens designers concerned.

3.5. Effects due to Excessive Exposure

During a series of tests which the Corporation conducted on a Philips three-plumbicon camera during December 1964, some difficulty was experienced with specular reflections, which may amount to many times the normal peak brightness of a scene, and charges were created which required many scans to remove them from the target. It appeared then that the use of excess beam current greatly reduced the visibility of the effect, and conversely a shortage of beam current greatly aggravated it.

Our anxiety on this point had been communicated to Philips prior to our visit, but it turned out on discussing the matter that there are actually two separate effects caused by excessive exposure. In order to make the discussion clear, it was agreed to describe one phenomenon as a 'highlight retention' effect and the other, which had been concerning the Corporation, as a 'comet tail' effect. These are discussed separately below.

3.6. Highlight Retention Effect

This effect was demonstrated to us by Philips using a blue-channel tube in a black-and-white camera, which was set up to view a test card illuminated with white light. The scene also contained a small lamp of brightness more than twenty times that of the white areas of the test card. The camera was panned and tilted so that the image of the lamp in the scene was caused to move over the target area. The scene was then changed for a plain grey area, and the locus of the image of the lamp was revealed in the picture as being brighter than the grey background. The persistence of such after-images is found to vary between several seconds and about ten minutes, but they can be removed completely by interrupting the beam for about one second.

The demonstration was repeated with a blue filter attached to the camera lens, and the neutral density filter, which had been placed over the small lamp, was removed to give the same target highlight brightness as in the previous test. In this case there was no after-image of the kind already described. The effects of highlight retention are not yet fully understood. Many tubes show no highlight retention at all, but where it is observed, the most common effect is that there is highlight retention to red or green light, but not to blue light. It is, however, primarily a production problem.

3.7. Comet Tail Effect

In the demonstrations described above to illustrate the highlight retention effect, we drew the attention of Philips to the fact that the bright lamp which should have appeared circular in shape in the reproduced picture was elongated in both cases behind the trailing edge of the image, thus giving it the appearance of a comet tail. This was the effect we have found to be produced by very bright specular reflections.

A number of tubes were examined in a test camera for comet tail effect by moving a small energised lamp about in the object plane. The tubes were found to differ somewhat in the extent to which they exhibited the effect, and they were also found to differ in the extent to which the effect was reduced by increasing beam stabilisation.

In some subsequent observations carried out with a colour camera at Philips Research Laboratories, it was found that the comet tail effect was displayed by the red and blue tubes, but not by the green tube, when the target was operated normally at 45 V, but that the effect could be removed by reducing the target voltage to about 10 V. There did not appear to be any important change in sensitivity as a result of reducing the target voltage, but Philips expressed the opinion that the lag of some tubes might be increased unacceptably if the target voltage were reduced to this low level, although this was not evident during our observations.

Since we first drew their attention to this effect, Electronica have investigated it in a number of production tubes. Electronica's results have been generally consistent with those obtained in BBC Research Department except that they had found a few tubes which behaved differently and were not amenable to reduction of comet tail by increased beam current. It was found that these abnormal tubes also exhibited peculiarities in the highlight retention effect and that the two effects might in some way, as yet undiscovered, be related. Philips are experimenting with an apparatus which would automatically increase the beam current whenever there was a period of brightness overload in the target. In subsequent investigations into means of avoiding operational difficulties from this cause, BBC Research Department have demonstrated the effects of a combination of reduced target potential and high beam current, rendering the tube almost completely immune to severe light overload. Electronica agree that the tube suffers no damage from operation at low target potential and good tubes operate perfectly well with only 15 V target potential, which at one time was the standard operating condition. The target potential was increased to 45 V because some tubes exhibit colour response changes at low target potential (see below) and there is also the possibility of inducing highlight retention effect or lag. The maximum charge that the target may acquire is necessarily limited to that which creates a potential equal to the applied target potential. It was found that if the latter was reduced to some point between 12 V and 20 V the tube could not accept a greater charge (no matter how bright the highlight) than a reasonable beam current could discharge sufficiently quickly to avoid comet tail effects. It therefore follows that if the tube may be operated with only 15 V target potential and stabilising beam current of, say, 0·8 μA, a knee in the characteristic results which will avoid all comet tail difficulties in extreme contrast conditions, e.g., a football-grandstand scene in which a very bright sky extends the contrast greatly without adding any wanted information to the picture.

The cost of doing this might be change of colour response in the blue channel or increase in lag if the blue tube was not a particularly good one. Otherwise with a good tube the picture should be virtually unimpaired although there would be a general loss of sensitivity which would probably not be serious since under the conditions considered there would be plenty of light available. It would be necessary to reduce the target potential of all three tubes in a colour camera in order to preserve registration and alignment.

It was agreed that both BBC Research Department and Electronica would continue the investigation and would liaise to provide confirmation that the proposal could be recommended as a means of overcoming comet tail effects when presented with scenes of abnormal contrast. It was emphasised that the separate-mesh tube was a sine qua non for working in this manner, since many (but not all) ordinary plumbicons lose resolution at beam currents in excess of 0·5 μA.

A draft clause covering this effect has been prepared for inclusion in Specification TV.153.

3.8. Colour Response

In some tubes there is a peculiar relationship between the blue sensitivity and the target potential. Good tubes have high blue sensitivity, even at very low target potentials but others require between 40 V and 45 V target potential before maximum blue sensitivity is reached and this is one of the most important reasons for the decision to operate normally at 45 V. A few tubes which early in their life have high blue sensitivity, even at 5 V target potential, may lose this quality as they get older although examination of the tube at 45 V target potential would reveal no change at all.

It was agreed that the required colour response for a separate luminance tube should be added to Specification TV.153 as soon as possible although this cannot be done until the BBC have agreed a luminance filter characteristic with whichever manufacturer builds four-tube cameras. It will probably be desirable to standardise on the mean black-and-white response declared by Philips and arrange for the luminance filter in the camera to shape the spectral response of the channel to the required characteristic.

3.9. Mechanical Tolerances

The importance of an immediate standardisation of glass thickness in the faceplate of the plumbicon was readily appreciated by Philips. It was pointed out to them that we already have lenses on order for plumbicon cameras and that it is imperative we know immediately the thickness of glass to be added in the rear conjugate distance of the lens. A discussion between Electronica and ELA resulted in an agreement that the total glass thickness would nominally be 7·2 mm and that when the basic faceplate thickness was increased, the additional faceplate would be reduced pro rata.

3.10. Tube Interchangeability

Philips hope in future to produce a common tube for use in all channels of a colour camera, but for the moment they are producing tubes for use in designated channels. Our discussions with them on the possible supply of tubes to the Corporation have been in these terms. We were naturally interested to establish what are the factors which determine the selection of tubes, and conversely what penalties in performance would result were it found necessary in an emergency to interchange tubes. They emphasised that tubes are not passed out from the factory unless they are completely suited to one particular purpose but it was agreed that

they may, nevertheless, be suitable for more than one application if some loss of sensitivity or picture quality is accepted. They emphasised that it is not possible to give hard and fast rules. However,

(a) Most RED and GREEN tubes can be used in the BLUE channel with up to 12 dB loss of sensitivity.

(b) More than 75% of all tubes designated BLACK-and-WHITE* can be used in RED or GREEN channels without any penalty. Some of these tubes, but not a very high proportion, can also be used in the BLUE channel.

(c) Almost all GREEN tubes can be used in the RED channel without penalty but RED tubes may be a little down in picture quality if used in the GREEN channel.

(d) BLUE tubes will most likely show highlight retention effects if used in RED or GREEN channels.

(e) Any tube designated BLACK-and-WHITE* or GREEN should prove satisfactory for use as a separate luminance tube.

The specification for a Y tube was discussed in detail and Electronica understood the requirements. This application is being added to those given in Specification TV.153. To give some idea of the losses of sensitivity involved by the interchange of tubes, Table 5 shows the sensitivity of typical tubes when used in channels other than those for which they were designated.

TABLE 5

CHANNEL FOR WHICH TUBE IS DESIGNATED	AVERAGE μA OF SIGNAL CURRENT PER LUMEN OF WHITE LIGHT BEFORE FILTER		
	RED FILTER	GREEN FILTER	BLUE FILTER
Red	80·0	181	14·2
Green	77·5	177	9·4
Blue	53·7	138	39·0

* Tubes designated BLACK-and-WHITE are intended for monochrome cameras and they may show highlight retention effects if stimulated only by saturated blue light as they would be in the blue channel of a colour camera. The statistical probability of this happening when they are used in a black-and-white channel is sufficiently small for the tubes to be satisfactory in this application.

At present some tubes are designated BLACK-and-WHITE because minor mechanical misalignments in the structure might make it difficult to obtain good registration with other tubes in a colour camera. The estimate 'more than 75%' mentioned in (b) would otherwise have been 100%. Electronica hope that this mechanical difficulty will be overcome in the near future.

4. CAMERAS EMPLOYING THE PLUMBICON TUBE

The opportunity was taken during the visits to discuss with both ELA and Philips' Research Laboratories certain aspects of the performance of the Philips' three-plumbicon colour camera which it was considered required further investigation. We also discussed Philips' intentions regarding black-and-white plumbicon cameras.

Those members of Philips with whom our discussions were mainly conducted were as follows:

Dr. de Vrijer (Research Laboratories)
Ir. Tan (Research Laboratories)
Ir. J.J.P. Valeton (ELA)
Ir. A.G. van Doorn (ELA)
Ir. Breimer (ELA)
Mr. B. Picauley (ELA)

4.1. Colour Cameras

4.1.1. Contrast Range and Flare

Doubt has been expressed about the ability of the plumbicon camera satisfactorily to handle high-contrast scenes, although this view was not supported by BBC experience. Coupled with this general criticism, was the suggestion that significant black level variations are caused by flare in the optical system of the Philips' camera.

As mentioned earlier, black level variations have, in fact, occurred due to flare within the faceplate of the tube itself and Philips have recently taken steps to reduce this by the addition of a 6 mm-thick window cemented to the faceplate of the tube. Such tubes were incorporated in one of the two cameras demonstrated in the Research Laboratories during our visit and were shown to convey a substantial improvement.

A scene was viewed by the camera fitted with tubes having the additional glass faceplate. The upper half of the picture consisted only of white cloud and sky, while the lower half included the upper part of a building, including a room which could be seen through a window. By panning the camera, it was also possible to view a scene of a switchbox in a rather dark enclosure which had a brightness of only 1/200 that of the sky. The camera showed that it was capable of reproducing these scenes in a subjectively satisfactory manner without the need for adjustment.

The above paragraphs state rather baldly the result of our observations made during one brief test, and it is perhaps worth discussing the factors which determine the contrast handling capabilities of cameras.

It is frequently necessary to reproduce accurately a wide range of brightness under conditions where part of the picture is occupied by a very much brighter object, e.g., the sky, which can if necessary be crushed in the reproduction without serious effect. It is, however, very desirable when extreme highlights occur that they should not impair other parts of the picture.

Two other very important factors which may affect the contrast handling ability of a camera are black shading or errors in the black level of a camera. These latter errors may be due either to electrical effects or to optical flare which has the effect of raising the minimum brightness which can be portrayed.

In comparisons between the plumbicon tube and the image orthicon, it is found that black shading in the image orthicon and restriction upon gamma correction imposed by its noise characteristic set a practical limit to the useful contrast range of about 30 : 1. The image orthicon, however, has the virtue that it can produce this 30 : 1 in the presence of relatively large areas of high brightness which may be as much as ten times the brightness to which wanted levels in the picture are set; this feature of the image orthicon is produced by the limiter action resulting from the non-linearity of the light transfer characteristic. At the same time, however, re-distribution effects will create a black halo surrounding highlights.

The superior noise performance of the plumbicon tube, and absence of flare and shading, permits gamma correction to take place over a considerably greater range than 30 : 1, and it is therefore able to handle greater wanted contrasts in the scene. At the present stage of development, however, the plumbicon can be set up normally to handle an excessive exposure in part of the picture of perhaps not more than three or four times the wanted highlight. In the presence of sky brightnesses in excess of this margin it would be necessary to re-adjust the operating conditions of the tubes in the camera. Three remedies are available:

(i) Reduce the lens aperture and increase video gain. This will crush the unwanted signals from the bright sky as in the case of the image orthicon, but the signal-to-noise ratio in the wanted parts of the picture will be impaired.

(ii) Reduce the potential of the targets to about 15 V. This will introduce a knee into the contrast law and the exposure can be adjusted until the wanted parts of the picture are below this knee while the unwanted parts are above it. This process reduces sensitivity of the tubes by about one stop.

(iii) Increase the beam current above the normal value to, say, 1·0 μA. In most existing tubes resolution will be impaired to some extent although it is believed that the introduction of the separate field mesh will overcome this effect.

In severe cases of excess highlight it would probably be found desirable to apply a combination of remedies (ii) and (iii) during the setting-up procedure before the programme. It is, however, believed that the overall picture quality, taking into account the effects of flare and shading, would still be better than in a camera with an image orthicon luminance tube.

It is therefore felt that the contrast handling ability of a colour camera equipped with plumbicon tubes (especially when fitted with anti-flare faceplates) will be substantially superior to that of the image orthicon camera when used in the studio. When used for outside broadcasts, however, some degradation of picture quality may be incurred in avoiding severe overload conditions imposed by bright skies should these be present and it is not possible firmly to say whether the nett result will invariably

be satisfactory. Extracts from the lighting records of over four years of outside broadcasting show that the majority of outside broadcasts have maximum contrast below 200 : 1 and therefore it would seem that a plumbicon camera equipped with the anti-flare faceplate would handle these without undue difficulty. There is, however, a small percentage of occasions on which the contrast between the sky and the darkest tones of interest in the scene amounted to 500 : 1. On these occasions it seems that it will be necessary to re-adjust the operating conditions of the plumbicons.

4.1.2. Fidelity of Skin Tones

We looked particularly closely at the ability of the three-plumbicon camera to reproduce skin tones in a subjectively satisfactory manner. It was found that with both the cameras which were available for tests in Philips Research Laboratories the pictures reproduced skin tones in such a way that they appeared to have a slightly unnatural appearance and subjectively this varied between a 'muddy' brown and a magenta cast. It was not possible by simple 'faking' of the camera balance or gamma controls to arrive at a desirable result.

In discussing this effect with Philips, it was suggested that the practice of lining up the camera on a 'white' object illuminated with tungsten light is to make the reproduction (6,500°K illuminant) appear too cold. This means, of course, that the blue component of the reproduced picture is enhanced and flesh tints will appear to have a magenta cast.

All this needs further investigation, but it should not be concluded that the ability of a plumbicon camera to reproduce skin tones satisfactorily is limited by the performance of the tube. Indeed, comparative tests[2] carried out some months ago between a three 3 in. image orthicon camera and an experimental Philips three-plumbicon camera did not then indicate any substantial differences on reproduction of skin tones.

4.1.3. Dichroic Tilt

Philips now state that they have found a means of reducing the green/magenta tilt, observed in the first production colour cameras, to the ratio 1·04 : 1 specified by us. This represents the minimum detectable error and is one-third of the original tilt, which was found to be unacceptable.

4.2. Black-and-White Plumbicon Cameras

As already stated in Section 2, Electronica expressed very clearly their intention to concentrate on the manufacture of plumbicons suitable for colour use and showed little interest in making black-and-white tubes. This attitude has been reflected in this country by Mullard's who have written to British camera manufacturers to dissuade them from embarking on the development of black-and-white cameras based on the plumbicon because of their inability to guarantee future supplies of tubes of this type. Despite this attitude, ELA, mainly through its overseas subsidiaries, has embarked on a programme of black-and-white plumbicon camera development and had considerable success at the 1965 N.A.B. Convention in Washington. This appears to indicate some division of opinion in this matter within the Philips' organisation between the tube and equipment manufacturing groups.

At the time of our visit in February, an international meeting was taking place in Eindhoven between representatives of the television equipment manufacturing groups in other countries with those of the parent ELA Group in Philips. Representatives attended from the United Kingdom (Peto Scott), the U.S.A., Germany and France. Part of the proceedings consisted of a demonstration of specimen items of equipment contributed by the subsidiary companies and these included both the Peto Scott studio black-and-white plumbicon camera and a plumbicon field camera made by North American Philips.

The Peto Scott camera, which is a turret design, is fairly well known to us and is relatively heavy, having regard to the fact that it makes use of a plumbicon tube. The weight of the camera, less lenses, is 88 lbs. to which 10 lbs. must be added for the weight of the detachable viewfinder.

Of some interest was the North American Philips 'Norelco' field camera which has a total weight of 65 lbs., including the zoom lens and viewfinder. The camera, in fact, consists essentially of three units, the lens unit, the camera proper and the viewfinder and is designed to break down into these three main packages, each of which weighs about 20 lbs., for ease of carrying.

The camera control unit weighs about 30 lbs. and up to 3,000 ft. of camera cable may be employed.

The camera may be used with both 10 × 18 mm and 10 × 25 mm Angenieux zoom lenses and a 1·6 : 1·0 range extender is being provided for the latter lens in order to make possible the use of longer focal lengths. It was stated that Rank Taylor Hobson are also arranging to produce a suitable lens for this camera. Provision has been made for a triple-function lens servo (weighing 8 lbs.) in the base of the camera body.

It appeared that quite a lot of development work had been done on this equipment by North American Philips and that the circuits employed differ in a number of ways from the simple HQ camera which formed the original prototype for this design.

It was decided in the course of the Eindhoven Conference that the 'Norelco' field camera would be adopted as a 'concern product', which means that its manufacture can be undertaken by companies in other countries within the organisation.

5. REFERENCES

1. BBC Specification TV.153, 'Plumbicon Camera Tube', Fifth Draft, 6th May 1965.

2. 'Comparisons Between Three Colour Television Cameras', Research Department Report No. T-132, Serial No. 1964/53.

CHS

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